THERMAL CONDUCTIVITY OF CEMENT KILN DUST FILLED EPOXY COMPOSITES

A Thesis Submitted In Partial Fulfillment of the Requirements

For The Degree Of

Bachelor of Technology

in

Mechanical Engineering

Submitted by

Pradeep Kumar Bal

(Roll No.110ME0279)

Department of Mechanical Engineering

National Institute of Technology

Rourkela

May 2014

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Under The Guidance of

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C E R T I F I C A T E

*This is to certify that the work in this thesis entitled THERMAL CONDUCTIVITY OF CEMENT KILN DUST FILLED EPOXY COMPOSITES by **Pradeep Kumar Bal** has been carried out under my supervision in partial fulfillment of the requirements for the degree of Bachelor of Technology in Mechanical Engineering during session 2013 - 2014 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.*

To the best of my knowledge, this work has not been submitted to any other University/Institute for the award of any degree or diploma.

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Pradeep Kumar Bal

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ABSTRACT

The present thesis deals with the estimation of thermal conductivity of epoxy composites embedded with Cement Kiln Dust (CKD) micro-fillers. Here Guarded heat flow meter test method is used to measure the thermal conductivity of CKD powder filled epoxy composites using an instrument Unitherm TM Model 2022 in accordance with ASTM-E1530. In the numerical study, the finite-element package ANSYS is used to calculate the conductivity of the composites. Three-dimensional spheres-in-cube lattice array models are used to simulate the microstructure of composite materials for various filler concentrations. This study reveals that the incorporation of Cement Kiln Dust (CKD) particulates results in enhancement of thermal conductivity of epoxy resin and thereby improves its heat transfer capability. The experimentally measured conductivity values are compared with the numerically calculated ones and with values which are obtained from various theoretical models. It is found that the values obtained for various composite models using finite element method (FEM) are in reasonable agreement with the experimental values and with theoretical models. These composites with CKD content ranging from 0 to 25 volume percentage (%) have been prepared and the thermal conductivities of the samples are measured experimentally. It is observed that for 15 volume % of CKD in epoxy matrix, the increase in thermal conductivity is about 36 % while for 25 volume % the increase in thermal conductivity is about 154 % which is reasonably higher compared to neat epoxy resin. An interesting fact is noticed from the table that measured values are in close approximation with the proposed model only up to 20 volume % after which a sudden jump in the value of measured k_{eff} is observed. This is due to the formation of conductive chain when the filler content in the matrix is increased beyond certain value. The volume % at which such sudden rise in the value of k_{eff} is observed is called percolation threshold.

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INTRODUCTION

Chapter 1

INTRODUCTION

1.1 **Definition of composite**

Composites are the combinations of two materials in which one of the materials is in the form of fiber sheets which is called the reinforcing phase and these are embedded in the other materials which are called the matrix phase [1]. A combination of two or more micro-constituents that differ in physical form and chemical composition and which are insoluble in each other can be termed as composites. To take the advantage of the superior properties of both materials without compromising on the weakness of either is the main objective for making composites [2]. Particulate filled polymer composites have become most important because of their wide applications in various fields of science and engineering for technological developments. Incorporation of inorganic fillers into a matrix does enhance various physical properties of the materials like mechanical strength, elastic modulus and heat transfer coefficient, thermal conductivity etc. In general, the mechanical properties of particulate filled polymer composites depend strongly on size, shape and distribution of filler particles in the polymer matrix [3]. Polymer composite materials have been found extremely useful for heat dissipation applications like in electronic packaging, in computer chips [4,5]. Polymer composites filled with metal particles has now become interest for many fields of engineering. Adding fillers to epoxy, plastics changes the behavior of polymers and a significant increase in the effective thermal conductivity of the system has been observed [6,7].

1.2 Overview of Composites:

A composite material is composed of reinforcement (fibers, particles or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical and thermal properties of the matrix. The newly combined materials hence exhibit better strength and other thermal properties than each individual material. By the type of material used for the matrix the composites are mainly classified. The reinforcing material can be either fibrous or non-fibrous (particulates) in nature. The composite materials have advantages over other conventional materials Due to their higher specific properties such as impact, tensile, flexural strengths, stiffness and fatigue characteristics the composite materials have a lot of advantage which enables for structural design applications and in a lot of fields. Epoxy resins are polyether resins containing more than one epoxy group capable of being converted into the thermoset form. In spite of the presence of a volatile solvent these resins on curing do not produce or create any volatile products. Applications for epoxy resins are extensive: adhesives, bonding, construction materials, composites, laminates, coatings, molding, and textile finishing. They have recently found uses in the spacecraft and air industries [8].

Usually Because of their following characteristics epoxy or polyester resin systems are used for encapsulating a variety of electronic components.

- They have a very high moisture resistance
- Thermally they are very much stable
- They have a very low cost

But unfortunately, they have

- A very high value of coefficient of thermal expansion
- A very low value of thermal conductivity

Cement Kiln Dust is mainly a by-product which is obtained from the cement manufacturing process. CKD which is partially calcined and unreacted raw feed-stock is a gray fine-grained structure. As it has many opportunities for reuse it has become a valuable resource. CKD is now-a-days is used as an agricultural liming agent. In this use CKD provides pH adjustment, potassium and other elements for plant growth. CKD is also extensively used as a drying agent and in the cleanup of oily wastes and for the processing of oil contaminated soil. It has been used as a mineral binder in asphalt production. Its liming capabilities have been used in a patented process for pathogenic control in sewage treatment and for pH adjustment in the manufacturing of recycled soil products [9].

Figure1.1 Cement Kiln Dust (CKD)

1.3 Types of Composite Materials:

Broadly, Composite Materials have been classified mainly into three groups on the basis of matrix material use.

1.3.1 Metal Matrix Composites (MMC).

1.3.2 Ceramic Matrix Composites (CMC).

1.3.3 Polymer Matrix Composites (PMC).

1.3.1 Metal Matrix Composites (MMC):

These composites consist of metal alloys reinforced with continuous fibers or particulates. They use metals as matrix materials and they have a higher temperature resistance than PMCs but they in general are heavier. The basic attributes of metals reinforced with hard ceramic particles or fibers are improved strength and stiffness. They also have improved creep and fatigue resistance, increased hardness, wear and abrasion resistance. Metal matrix composites have wide range of applications in combustion chamber nozzle, housings, tubing, cables, heat exchangers, structural members due to their above attributes.

1.3.2 Ceramic Matrix Composites (CMC):

Ceramic matrix composites (CMCs) have a ceramic matrix such as calcium, aluminum silicate reinforced by fibers such as carbon/silicon carbide. To increase the toughness is one of the objectives in producing CMC. Naturally it is found that there is a concomitant improvement in stiffness and strength of ceramic matrix composites and stiffness of ceramic matrix composites. Now-a-days in many respects, CMC are considered as a dream of design engineer's.

1.3.3 Polymer Matrix Composites (PMC)

Polymeric matrix composites are generally inexpensive, corrosion resistant and easy to form into complex shapes, and they have low densities. They are increasingly now-a-days used in automotive, aerospace and in many other commercial applications. In general the mechanical properties of polymers are inadequate for many structural purposes; particularly their strength and stiffness are very low when these are compared to metals and ceramics. Secondly, high temperature and high pressure are not required in the processing of polymer matrix composites. Also simpler equipments are mainly required for manufacturing polymer matrix composites. Only for this reason the development of polymer composites took place rapidly and it became more and more popular for structural applications.

1.4 Types of Polymer Composites:

Broadly, polymer composites are generally classified into three categories on the basis of reinforcing material. They are given as;

1.4.1 Fiber reinforced polymer (FRP).

1.4.2 Particle reinforced polymer (PRP).

1.4.3 Structural polymer composites (SPC).

1.4.1 Fiber Reinforced Polymer (FRP)

These are of two following types

- Containing discontinuous fibers
- Containing continuous fibers

Fiber reinforced composites contain reinforcements having length much greater than their cross-sectional dimensions. If its properties vary with fiber length it is considered as a short or discontinuous fiber. Fibers and matrix are generally the main constituents of common phase of fiber reinforced composites. Fibers are the main source of strength in composite. Main function of fibers is reinforcement and while matrix glues all the fibers together in shape and transfers stresses (load) between the reinforcing fibers.

Among all resin material epoxy and Polyester are most widely used. Epoxy resin, which has higher adhesion and less shrinkage than polyesters resin, comes in second for its higher cost.

1.4.2 Particle Reinforced Polymer

Particles are used basically for increasing the ductility and decreasing the modulus of the matrix in this kind of polymers. Particles are also used for reducing the cost of the composites. Matrices and Reinforcements can be processed easily and they can be common inexpensive materials. Many ceramics are good electrical and thermal insulators. Some ceramics materials have special properties likes magnetic, piezoelectric and superconductivity at very low temperatures. They are brittle is the only disadvantage of this type of composites. Automobile tire is an example of this type of composite.

1.4.3 Structural Polymer Composites

The laminar composites are held together by matrix and composed of layers of materials. Sandwich structures also do fall under this category. Previously, we have seen that polymers have replaced many of the conventional metals or materials in various applications. It has been possible due to the advantages of the polymers over conventional materials. Ease of processing productivity and cost reduction are the most important advantages of using polymers in composite. Fiber reinforced polymers offer advantages over other conventional materials when specific properties are compared. Due to these reasons these composites are used in aircraft and in various diverse fields.

1.5 Laminate Definition:

A lamina is a single flat layer of unidirectional fibers arranged in a matrix form. A laminate is a stack of plies of composite material. Each layer can be made up of different material systems and laid at various orientations. The average properties of a composite depend on the individual properties of the constituents of that composite. These properties are mainly stiffness, moisture expansion and thermal coefficient, strength. Laminate composites are composed of layers of materials held together by matrix. Generally, these layers are alternatively arranged for the better bonding between reinforcement and the matrix. According to the use of these laminates can have unidirectional/bidirectional orientation of the fiber reinforcement .The different types of composite laminates are unidirectional, cross-ply and symmetric laminates. High strength and stiffness usually require a high proportion of fibers in the composite. This is obtained by aligning a set of long fibers in a thin sheet .

1.6 Comparison between composite and conventional material

Some general differences between composite and conventional material have been observed and these are described below.

- High corrosion resistance of fiber composites contribute for reducing life-cycle cost.
- Fiber composites can be tailored to meet performance needs and complex design requirements like in aero-elastic loading the wings and in the vertical & the horizontal stabilizers of aircraft.
- They provide service for a very long period.
- Impact energy values for aramid-epoxy composite are significantly much higher than those for aerospace aluminum alloy and carbon fiber.
- Because fiber reinforced plastic can be designed with excellent structural damping features, they are less noisy and provide lower vibration transmission than metals.

1.7 Application of composite in various fields:

There are huge areas of application of polymer composite in various fields. In polymer composites polymers used are epoxy, phenolic, acrylic, urethane and polyamide. Each of group has specific characteristics and advantages over other polymers, therefore application is based on requirement. The selection is fulfilled by properties like low cost, ease in designing and production of functional parts etc. By using a variety of reinforcements polyester has continued to be used in improving the system and other applications. Thermoplastics are combined with reinforcing fibers in various proportions as the requirements. Thermo plastics are used to produce several parts of vehicle. Selection of the material is made from the volume required apart from cost-effectiveness and mechanical strength. An application of polymer matrix composites is very large from tennis racquets to the space shuttle. Rather than enumerating only the areas in which polymer based composites are used, a few examples have been taken from each industry. Emphasis has been placed on why a composite material is the material of choice.

Aircraft:

The military aircraft industry has mainly led the use of polymer matrix composites. In the field of commercial airlines, the use of composites has been conservative because of safety concerns. Use of composites is limited to secondary structures such as rudders and elevators made of graphite/epoxy for the Boeing 767 and landing gear doors made of Kevlar- graphite/epoxy. In panels and floorings of airplanes composites are used. Helicopters and tilt rotors use graphite/epoxy and glass/ epoxy rotor blades that not only increase the life of blades by more than 100% over metals but also increase the top speeds.

Space:

Main factors make composites the material of choice in space applications is that: strength, high specific modulus and dimensional stability is one of most important mechanical properties that need to satisfy the required condition, during large changes in temperature in space. For the space shuttles, graphite/ epoxy were chosen primarily for weight savings and for small mechanical and thermal deflections concerning the remote manipulator arm which deploys and retrieves payloads.

Sporting goods:

The optimum design of sports equipment requires the application of a number of disciplines not only for enhanced performance but also to make the equipment as user-friendly as possible from the standpoint of injury avoidance. In designing of sports equipment the various characteristics of materials must be considered. Among these characteristics are ductility, density, strength, fatigue resistance, toughness, modulus (damping) and most important are cost. To meet the requirements of sports equipment the materials of choice often consist of a mixture of material types -metals, ceramics, polymers and composite concepts.

Medical devices:

Applications here include the use of glass-Kevlar/epoxy lightweight face masks for epileptic patients. Artificial portable lungs are made of graphite-glass/epoxy so that a patient can be mobile.

Chemical Industry:

Supplemented by the advantages of composites of lightweight, mould ability, fire resistance properties resistance to chemicals has made the material popular in the chemical industries. Composites material are used in storage tanks, scrubbers, ducting, exhaust stacks, pumps, piping, blowers, columns and reactors etc.

Marine:

The application of fiberglass in boats is well known. Hybrids of Kevlar-glass/epoxy are now replacing fiberglass for improved weight savings, vibration damping, and impact resistance. Kevlar-epoxy by itself would have poor compression properties.

Commercial:

The Fiber-reinforced polymers have many other commercial applications. Some brooms used in pharmaceutical factories have handles that have no joints or seams, the surfaces are smooth and sealed.

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Chapter 2

LITERATURE REVIEW

Chapter 2

LITERATURE SURVEY

The purpose of this literature review is to provide background information on the issues to be considered in this thesis and to emphasize the relevance of the present study. This topic includes brief review on:

1. Particulate Reinforced polymer composites.
2. Thermal Conductivity of Polymer composites.
3. Thermal Conductivity Models.

2.1 On particulate filled polymer composites:

For the improvement of wear resistance type mechanical properties hard particulate fillers which consists ceramic or metal particles and fiber fillers which are made of glass are used [11]. In various industrial applications like in heaters, in electrodes, composites with thermal durability at high temperature etc. various kinds of polymers and polymer matrix composites which are reinforced with metal particles are used. Due to their low density, high corrosion resistance, ease of fabrication and low cost these types of engineering composites are used. At the cost reduction and stiffness improvement the inclusion of inorganic fillers into polymers for commercial applications is primarily aimed [12]. In this regard, Yamamoto et al. [13] reported that the structure and shape of silica particle have significant effects on the mechanical properties of composites. Nakamura et al. [14-15] discussed the effects of size and shape of silica particle on the strength.

2.2 On Thermal Conductivity of Polymer composites:

For the thermal conductivity of composite systems Progelhof et.al [16] had predicted by presenting a detailed view on methods and models. Procter and Solc [17] had investigated thermal conductivity of various polymer composites which are filled with different types of fillers. The thermal and mechanical properties of copper powder filled poly-ethylene composites are found by Tavman [18]. Mamunya et. Al [19] also reported the improvement in electrical and thermal conductivity of polymers filled with metal powders. Weidenfeller et al. [20] studied the effect of the interconnectivity of the filler particles and its role in the thermal conductivity of the composites. Tekce et. al [21] had noticed that how shape factor of fillers strongly influences the numerical value of thermal conductivity of various types of composites. Kumlutas and Tavman [22] carried out various numerical and also experimental study for determining thermal conductivity of particle filled polymer composites; Patnaik [23] had reported that there exist a co-relation between thermal conductivity and wear resistance of particulate filled composites.

2.3 On Thermal Conductivity Models

In the last chapter for finding effective thermal conductivity of particulate filled polymer composites various theoretical as well as experimental models have been described. It is very easier and simpler if we assume models in which materials are arranged in either parallel or series with respect to heat flow, from which the upper or lower bounds of effective thermal conductivity can be obtained.

For the parallel conduction model:

$$k_{eff} = (1-\phi_f)k_p + \phi_f k_f \tag{2.1}$$

For series conduction model

$$1/k_{eff} = (1-\phi_f)/k_p + \phi_f / k_f \tag{2.2}$$

The correlations presented by equations (2.1) and (2.2) are derived on the basis of the Rules of Mixture (ROM). A new model for x filled polymers was proposed by Agari and Uno [24] had proposed a new model for X filled polymers, that uses series and parallel conduction heat transfer mechanisms. According to this model, the expression that governs the thermal conductivity of the composite is:

$$\text{Log}(k_c) = \text{Ø}*C_2*\log(k_f) + (1-\text{Ø})\log(C_1 k_m) \qquad (2.3)$$

Where, C_1, C_2 are experimentally determined constants of order unity. Generally this semi-empirical model seems to fit the experimental data well. However, for determination of the necessary constants adequate experimental data is needed for each type of composite. The exact expression for the effective thermal conductivity for an infinitely dilute composite of spherical particles is given as

$$\frac{K}{K_c} = 1 + \frac{3*(K_d - K_c)}{(K_d + 2*K_c)} \qquad \textbf{(2.4)}$$

$$\frac{K_{eff}}{K_p} = \frac{K_f + 2K_p + 2\emptyset_f(K_f - K_p)}{K_f + 2K_p - \emptyset_f(K_f - K_p)} \qquad \textbf{(2.5)}$$

Where $\emptyset_f$ is the volume fraction; K is the thermal conductivity of composite, K_c thermal conductivities of continuous-phase (matrix), K_d is the thermal conductivity of dispersed-phase (filler). Equation (2.4) and (2.5) are known as Maxwell equation for dilute composites. By using this model for low filler concentrations thermal conductivity is predicted. When there is an increase in filler concentrations, conductive chains is started to form because the particle starts to come in contact with each other, this conducting chain is in the direction of heat flow, that is the reason why the value of effective thermal conductivity are underestimated for the above model. All the models discussed above calculated effective thermal conductivity on the basis of volume fraction of the filler but none of the model has taken care of the arrangement of the filler into the matrix. On that basis, authors proposed a theoretical model considering distribution of particles into the matrix as well along with the volume fraction of filler in their earlier work .The expression for calculating effective thermal conductivity proposed by authors is given by

$$k_{eff} = \frac{1}{\frac{1}{k_p} - \frac{1}{k_p}\left(\frac{6\phi_f}{\pi}\right)^{\frac{1}{3}} + \frac{4}{\left(k_p\left(\frac{4\pi}{3\phi_f}\right)^{\frac{2}{3}} + \left(\frac{2\phi_f}{9\pi}\right)^{\frac{1}{3}} 2\pi\left(k_f - k_p\right)\right)}} \tag{2.6}$$

Where φ_f represents the volume fraction and *k* is the thermal conductivity, suffix *f* and *p* are for filler and matrix material.

Chapter Summary

This chapter has provided an exhaustive review of research works on particulate reinforced polymer composites, thermal conductivity of polymer matrix composites, on thermal conductivity models of CKD filled composites reported by various investigators. The next chapter discusses experimental planning, characterization details and the finite element analysis.

Chapter 3

MATERIALS AND METHODS

Chapter 3

MATERIALS AND METHODS

Here the materials and the methods which are used for processing of the composites have been described. It gives a brief idea about thermal conductivity tests and characterization test of the material to which a material is subjected. Here the numerical method for finding thermal conductivity is based on finite element method.

3.1 Numerical Analysis: ANSYS and Finite Element Method (FEM):

FEM was introduced at first by Turner et al. in 1956. It is used for approximate solutions to a variety of engineering problems with having general boundary conditions. Now-a-days it has become very much essential in modeling and designing various physical phenomenons. The basic principle of FEM is mainly based on the putrefaction of dominion into a finite number of sub-domains for which a methodical approximate solution is obtained by the application of weighted or vibrational enduring methods. First FEM reduces the problem into a predictable number of unknowns by dividing the dominion into elements and by expressing the unknown field variables in terms of the assumed resembling functions within each element. These are also called as interpolation functions. Nodes connect adjacent elements and these are generally located along the element boundaries. The method becomes more flexible due to the discretization of the irregular domains with finite elements. Thus it is a numerical method which can be used to obtain solutions to a large range or class of engineering problems which involves heat transfer, fluid flow, stress analysis etc.

3.2 Advantages of the FEM over other numerical methods:-

- No geometrical restrictions are there in FEM. It can be applied to any shape of the products.

- Load and boundary conditions can be applied to any portion of the body.
- Problems related to domain which consist of more than one material can be easily analyzed.
- This method is applicable to all types of boundary conditions.
- By choosing higher degree of polynomials, the accuracy of the solution can be improved.
- By mesh refinement the analysis result is easily improved.
- The structure of FEM closely resemble like the actual body which is to be analyzed.
- The algebraic equations can be easily generated and solved on a computer.
- Finite element method is easy to produce the detailed visualizations of a complex problem.

3.3 MATERIALS:

(a)Matrix Material:

The most commonly used resins are Epoxy resins. They contain epoxide groups with low molecular weight organic liquids. Because of its low density (1.2 gm. /cc) it is chosen primarily. In its ring Epoxy has three members in its rings. There are one oxygen and two carbon atoms. The epoxy is made mainly from the reaction of epichlorohydrin with phenols or aromatic amines. It has a low thermal conductivity value (0.363W/m. K).

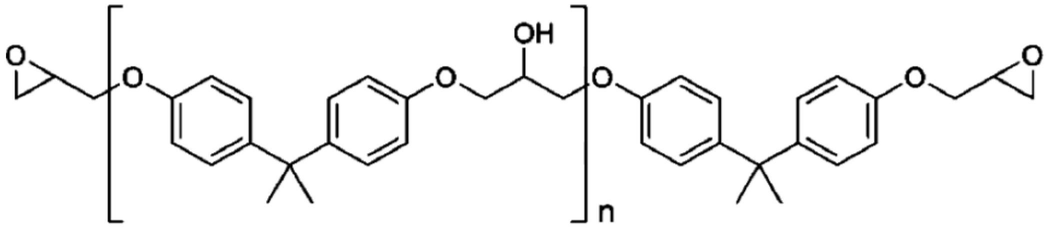

Fig 3.1: Unmodified epoxy pre polymer resin chain.

(b)Filler material:-

CKD is generally a gray fine-grained mixture of unreacted and partially calcined raw feed-stock. It has a thermal conductivity and density values (3.1 W/m .K and 2.34gm/cc respectively).

Fig 3.2: Epoxy Resin

Key Properties:

- Higher value of thermal conductivity
- Very low value of thermal expansion
- Good ability to resist thermal shock
- High value of electrical resistance
- Very low value of density
- Non-toxic in nature

3.4 METHOD:

Composite fabrication:

- Generally the composites are cast conventionally by hand-lay-up techniques with different filler concentrations.
- The low curing temperature epoxy resins and corresponding hardener (HY951) are mixed in a ratio of 10:1 micro-sized CKD particles with an average size of 100 micron.
- Composites of six different compositions 0, 5.3, 12.83, 17.86 and 23.1 volume% of Cement Kiln Dust are made.
- At room temperature the castings are left cure for about 24 hours after which the cups are broken and samples are taken out.

TABLE 3.1: LIST OF PARTICULATE FILLED COMPOSITES FABRICATED BY HAND-LAY-UP TECHNIQUES.

Samples	**Composition (for CKD filled epoxy)**
1	Epoxy + 0 vol. % (0 wt %) CKD Filler
2	Epoxy + 3 vol. % (5 wt %) CKD Filler
3	Epoxy + 6.2 vol. % (10 wt %) CKD Filler
4	Epoxy + 9.51vol. % (15 wt %) CKD Filler
5	Epoxy + 13 vol. % (20 wt %) CKD Filler
6	Epoxy + 17 vol. % (25 wt %) CKD Filler
7	Epoxy + 20.3 vol. % (30 wt %) CKD Filler

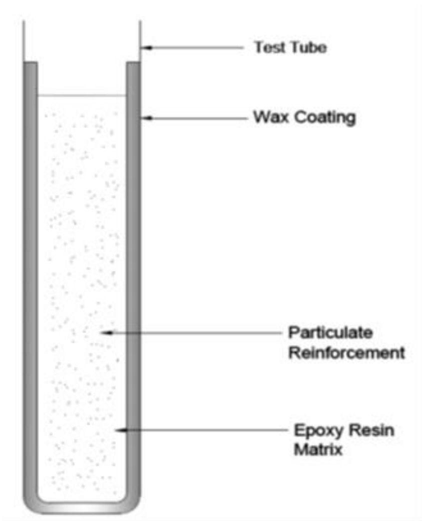

Fig. 3.3 Preparation of particulate filled composites by hand-lay-up technique

3.6 Experimental Determination of Thermal Conductivity:

For measuring thermal conductivity of a composite Unitherm™ Model 2022 is mainly used. Small test samples are generally required for the measurement. By this liquids and various pastes like non-solids by using particular containers can be tested. By using multi-layer techniques thin films can also be treated accurately. Mainly tests are conducted in accordance with **ASTME-1530** standard.

Operating principle of Unitherm™2022:

Between two polished surfaces under a uniform compressive load a material sample is held and each part is controlled with different temperatures. A calibrated heat flow transducer is the lower part. The heat flow takes place from the top part to the lower part by passing through the length of the body which establishes a temperature gradient along the length. The temperature difference across the sample is measured after the system attains thermal equilibrium by the used measuring instrument. For calculating the value of thermal conductivity these values and the sample thickness are used. By temperature sensors the temperature drop across the length of the sample means at either sides of the sample is measured.

The heat conduction is measured by:-

$$Q = \frac{K*A*(T_1-T_2)}{X} \tag{3.1}$$

Where Q is termed as the heat flux (W), K is termed as the thermal conductivity (W/m-K), A is termed as the cross-sectional area (m^2), T_1-$T_2$is termed as the difference in temperature (K), X is termed as the thickness of the sample (m). The thermal resistance of a sample can be given as,

$$R = \frac{X}{(K*A)} \tag{3.2}$$

Where, R is the resistance of the sample between cold and hot surfaces (m^2-K/W).

From Equation 3.2 it can be written as

K=X/ ((R*A)) (3.3)

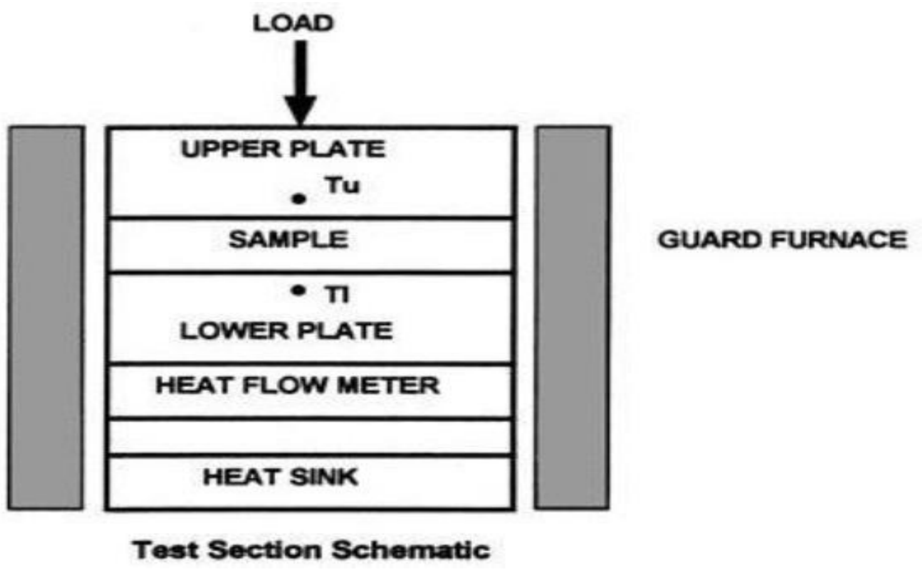

Fig3.4**:** Determination of thermal conductivity using unitherm™ model 2022

Q value is measured by the heat flow transducer and by the heat flow transducer the temperature difference is obtained between the lower and the upper plate in Unitherm 2022. By using this, the thermal resistance can be calculated between the lower and the upper surfaces of the material. As the cross sectional area and length of the specimen or sample are known to us by using the Equation 3.3 the effective thermal conductivity of the sample can easily be calculated.

Chapter Summary

This chapter provides:

- A brief explanation regarding FEM
- The descriptions of various materials which are used in the experiment
- The details regarding the fabrication of the composites by hand lay-up technique

The next chapter presents the results of the numerical analysis and experiments conducted to measure the thermal conductivity of the polymer composites.

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Chapter 4

RESULT AND DISCUSSION

Chapter 4

RESULTS AND DISCUSSION

The results from the numerical analysis and from the conducted experiments have been presented here in this chapter to study the thermal conductivity of the polymer composites.

4.1 EFFECTIVE THERMAL CONDUCTIVITY (K_{EFF}) OF CKD FILLED WITH EPOXY MATRIX COMPOSITES:

4.1.1 Description of the problem:

For the application of composite materials and for functional design the determination of effective thermal conductivity is very much important. Microstructure of composites is a property which can be efficiently controlled which influence the effective properties of the composites. Due to high degree of symmetry which is embedded in the system can be more easily analyzed with periodic structures in the system. Thermal analysis which is carried out for conductive heat transfer through the composite body by using finite element program ANSYS through the composite body. Here for six different filler concentrations in order to make a thermal analysis, physical models with spheres in a cube lattice array in 3-D have been used for the simulation of micro structure of the composite material. The effective thermal conductivities of these epoxy composites filled with CKD up to about 23.1 % by volume is numerically determined using ANSYS.

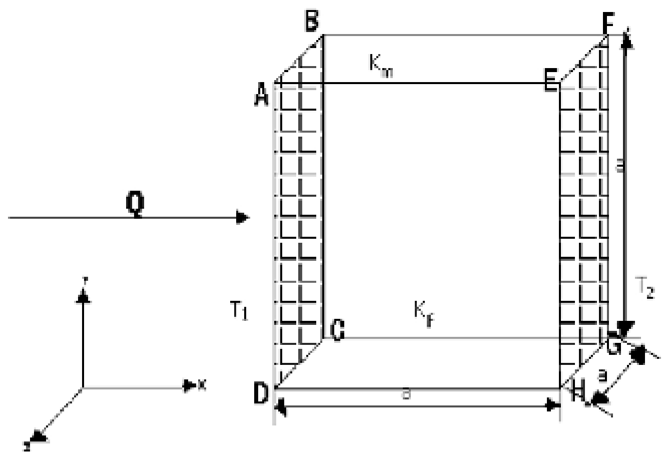

Fig.4.1 Boundary conditions

4.1.2 Numerical Analysis

Here at starting the temperature at the nodes which are along the surface ABCD are kept 100° C (T1).Here the ambient temperature is taken as 30°C. The convective heat transfer coefficient at this ambient condition for the taken model at the faces ABCD and EFGH are taken as 25 W/m^2-K. The heat flow takes in longitudinal direction or in the direction perpendicular to both the faces ABCD and EFGH. The other four faces except ABCD and EFGH for the taken cube as shown in figure are kept as insulated. The nodes which are in the interior region the temperature at those nodes can be determined by the help of finite element package of ANSYS.

A typical 3-D model with a particle concentration of 23.1 volume % showing arrangement of spherical fillers within the cube shaped matrix body has been illustrated in Fig.4.2. The temperature profiles obtained from FEM analysis for the composites with particulate concentrations of 0, 5.3, 12.83, 17.96 and 23.1 vol. % have been presented in Fig. 4.3 - Fig.4.8 respectively.

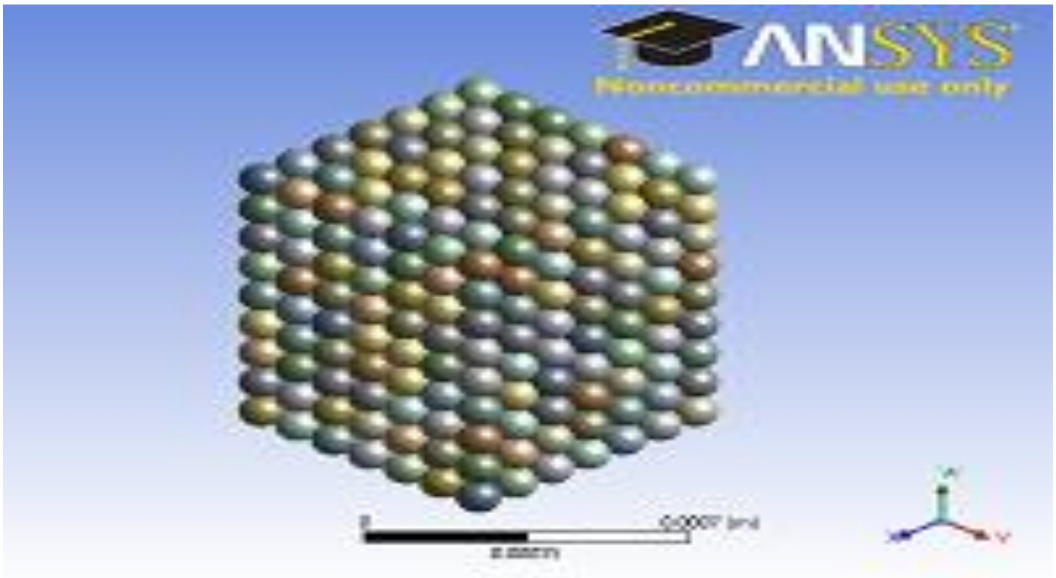

Fig 4.2Geometric model of Cement Kiln Dust (spheres) in epoxy   matrix (cube) at 23.1volume %.

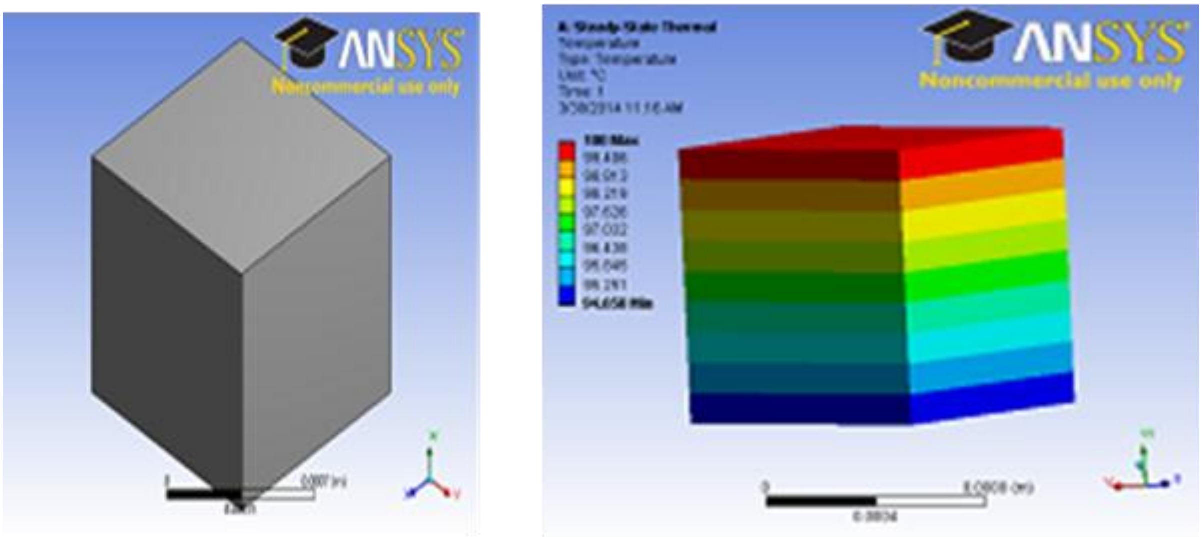

Fig 4.3: Temperature profile of CKD (spheres) in epoxy matrix (cube) at 0 volume %

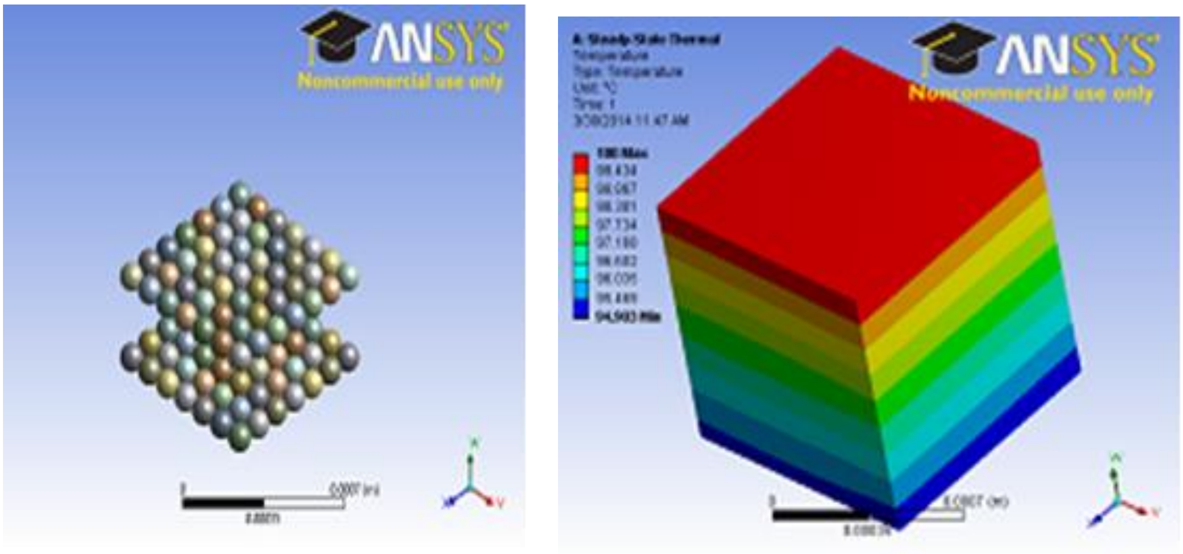

Fig 4.4: Temperature profile for composite with particle concentration of 5.3 volume %.

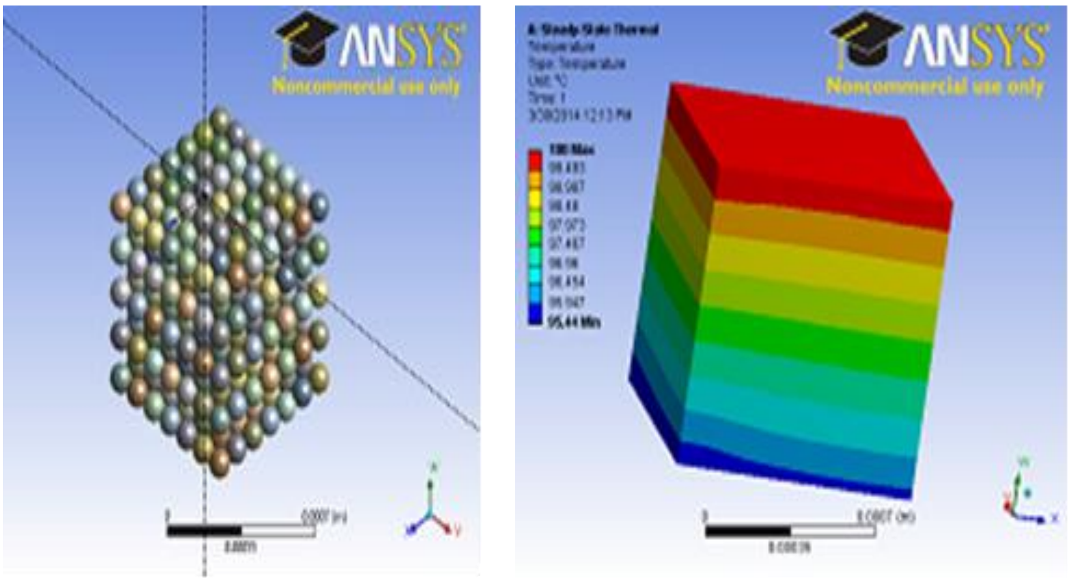

Fig 4.5: Temperature profile for composite with particle concentration of 12.83 vol.

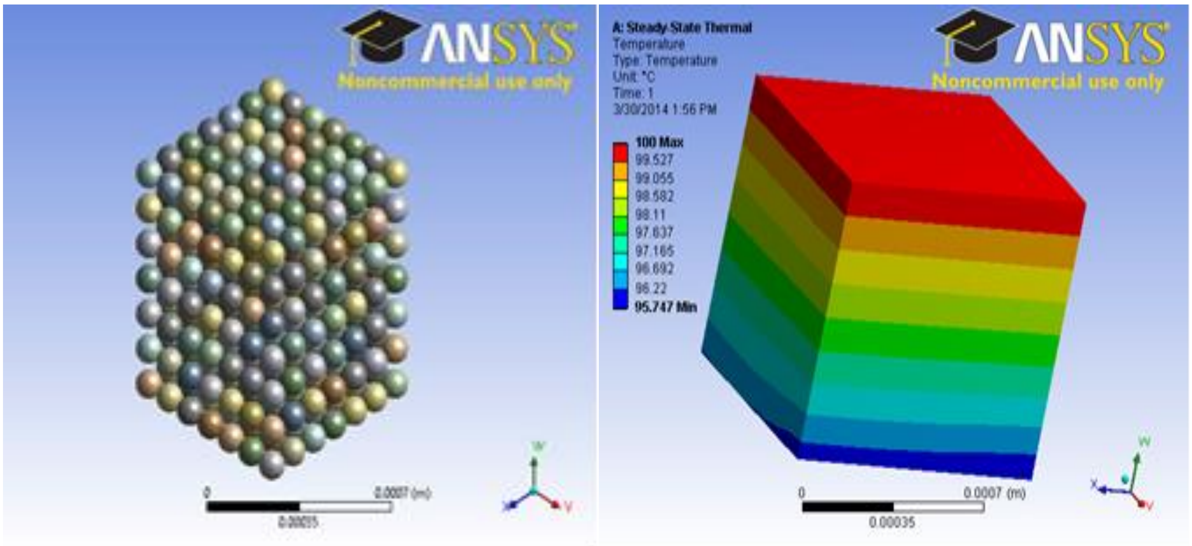

Fig 4.6: Temperature profile for composite with particle concentration of 17.96 volume %.

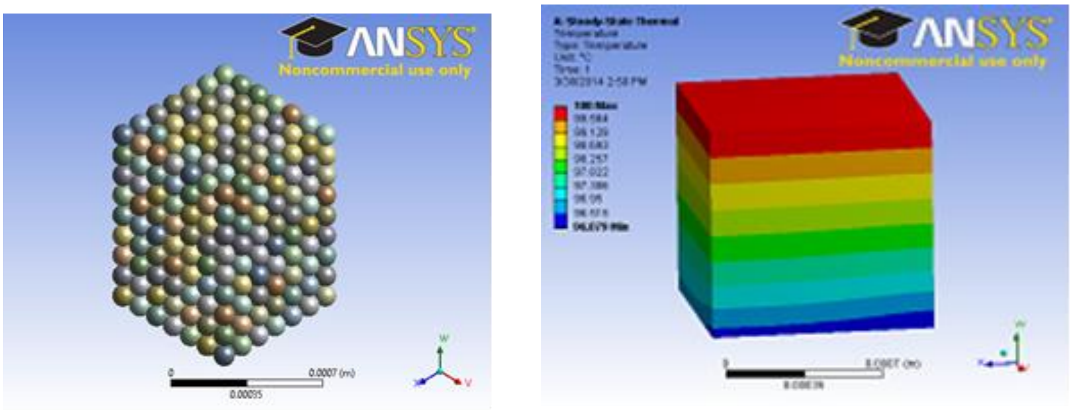

Fig 4.7: Temperature profile for composite with particle concentration of 23.1 volume %.

The values of effective thermal conductivities of the particulate filled epoxy composites with varied proportions of CKD obtained using rule-of-mixture model, Maxwell's equation and ROM series model and from the Proposed model have been presented in Table 4.1. It presents a comparison among the results obtained by using these models with regard to the corresponding values of effective conductivity obtained experimentally.

TABLE 4.1: EFFECTIVE THERMAL CONDUCTIVITY VALUES OBTAINED FROM DIFFERENT METHODS.

sample no	CKD VOL.%	Effective Thermal Conductivity of the composites (w / m.k)				
		ROM Series Model	Maxwell model	Proposed model	FEM	Experimental
1	0	0.363	0.363	0.363	0.364	0.363
2	5	0.500	0.404	0.388	0.380	0.378
3	10	0.637	0.447	0.448	0.408	0.403
4	15	0.773	0.495	0.523	0.442	0.494
5	20	0.918	0.545	0.598	0.484	0.587
6	25	0.988	0.595	0.661	0.53	0.92

TABLE 4.2 PERCENTAGE ERRORS WITH RESPECT TO THE EXPERIMENTAL VALUE WITH RESPECT TO EXPERIMENTAL METHOD.

Sample no	vol %	Percentage errors with respect to the experimental value %				
		ROM Model	Maxwell model	Proposed model	FEM	Experimental
1	0	0	0	0	0.08	0.363
2	5	32.25	6.87	2.645	0.06	0.378
3	10	58.04	10.912	11.166	1.31	0.403
4	15	56.47	0.02	5.87	10.7	0.494
5	20	56.38	-7.122	1.879	-17	0.587
6	25	7.391	-35.322	-28.152	-42	0.92

TABLE 4.3 COMPARISON OF THERMAL CONDUCTIVITY BY FEM RESPECT TO EXPERIMENTAL METHOD

Sample no	Vol % of CKD	Effective thermal conductivity of composites Keff(W/m-K)		Percentage errors with respect to the experimental value %
		FEM	Experimental	
1	0	0.36	0.363	0.0358
2	5	0.38	0.3780	0.0478
3	10	0.4	0.403	1.31
4	15	0.44	0.494	-10.47
5	20	0.49	0.587	-17.6
6	25	0.53	0.92	-42.39

The simulated values of effective thermal conductivity of the composites obtained by FEM analysis are presented in Table 4.3 along with the corresponding values which are obtained from experimental method.

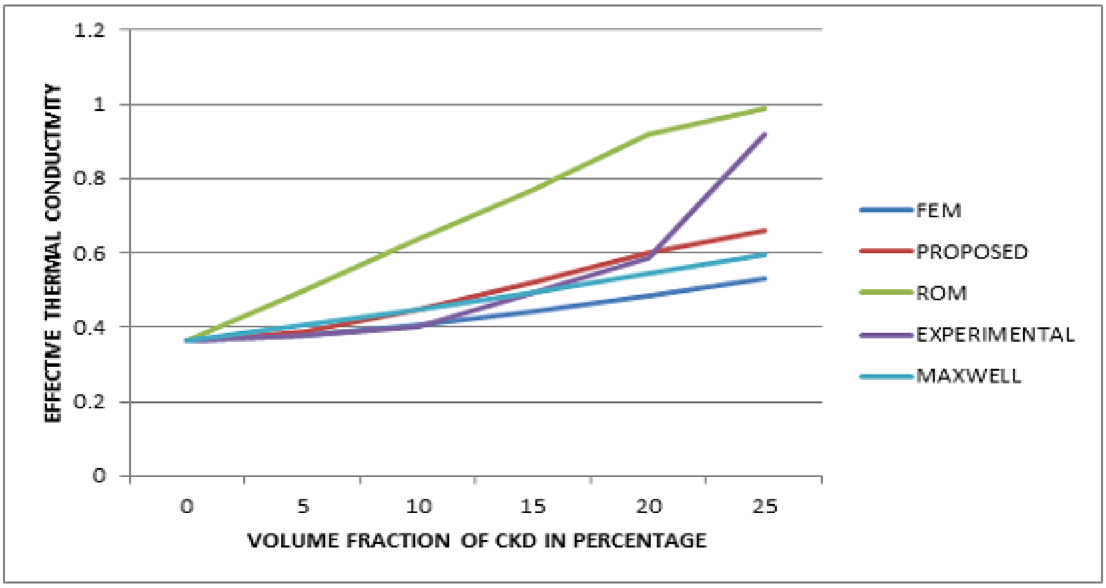

Fig. 4.8: Effective thermal conductivity of the composites as function of CKD content in line diagram

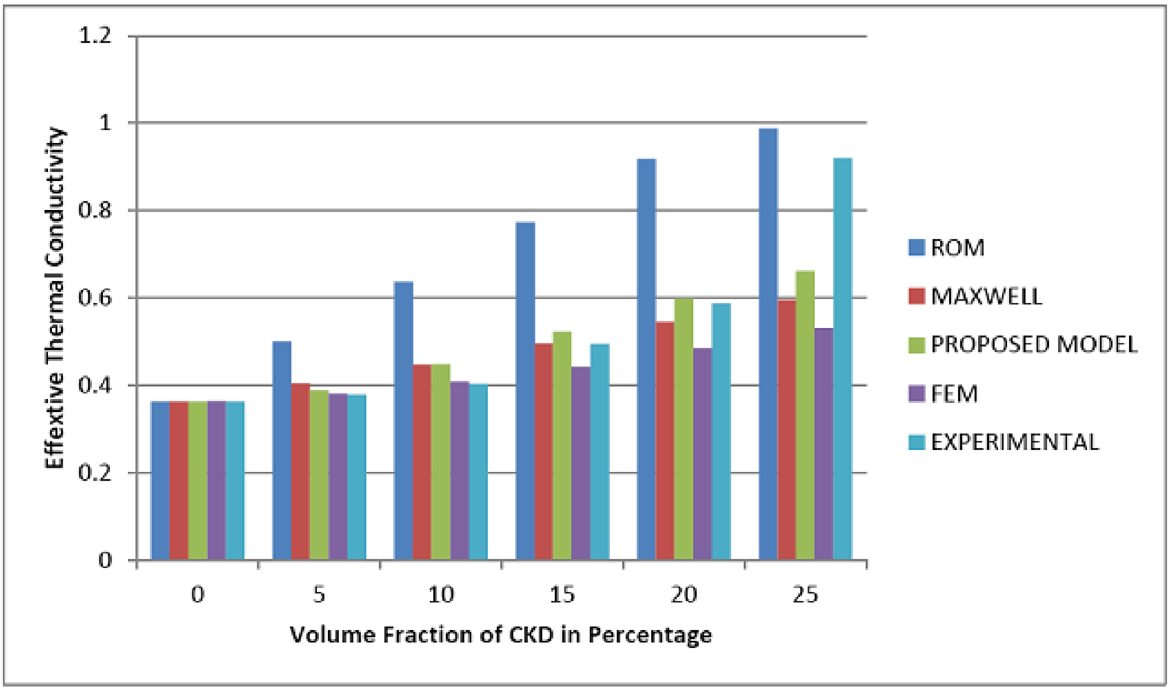

Fig. 4.9: Effective thermal conductivity of the composites as function of CKD content in histogram.

For composites of different filler content it is found that the results which are obtained from finite element analysis by taking sphere in cube composite model are very much closer to the experimentally measured values of the effective thermal conductivities and with those obtained from various theoretical models. The percentage errors which are associated with the FEM values with respect to the experimental values have been given in Table 4.3. On comparing with the experimentally measured values, it is further noticed that while the rule-of-mixture, Maxwell's equation and FEM underestimate the value of thermal conductivity, FEM overestimates the value with respect to that of experimental ones. It leads to a conclusion that for a particulate filled composite of this kind the FEM can very well be used for predictive purpose in determining the effective thermal conductivity for a wide range of particle concentration. Fig. 4.8 compares the FEM (sphere- in-cube model) simulated results of thermal conductivity with those have been found from experiments. It also presents the variation of effective thermal conductivity as a function of the CKD content in the composite.

The difference between the measured values and the simulated value of conductivity may be attributed to the fact that some of the assumptions taken for the numerical analysis are not real. The real shape of CKD particles is irregular in shape but here it has been assumed that the shape is spherical. It is seen that the incorporation of CKD results in increase in thermal conductivity of neat epoxy resin. With addition of 15 vol. % of CKD, the thermal conductivity is increased by about 35 % and with addition of 25% of CKD, the thermal conductivity is increased by about 154 % when compared with neat epoxy resin.

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Chapter 5

CONCLUSIONS AND FUTURE WORK

CONCLUSIONS AND SCOPE FOR FUTURE WORK

5.1 Conclusions

This investigation has led to the following specific conclusions:

1. By hand-lay-up technique the successful fabrication of micro sized CKD filled epoxy composites is possible.
2. Finite element method (FEM) can be employed for determining effective thermal conductivity of these fabricated composites with different volume fraction of CKD.
3. The numerical values of effective thermal conductivity obtained for various composite models with different volume fraction of CKD from FEM agree reasonably with the experimental values for a range of filler contents from 0 vol. % to 20 vol. %.
4. The values of thermal conductivity obtained from FEM are found to be more accurate (with respect to the experimental values) than the calculated values from existing theoretical models such as Rule of mixture, Maxwell's equation, Proposed model.
5. Incorporation of micro-sized CKD results in significant increase of thermal conductivity of epoxy resin. With addition of 15 vol. % of CKD, the thermal conductivity of epoxy increases by about 35% and with addition of 25 vol. % of CKD the increases by about 154%.
6. As Incorporation of CKD results in enhancement of thermal conductivity of epoxy resin So, It improves its heat conduction capability.
7. These new class of C.K.D filled epoxy composites can be used for applications such as electronic packages, electrical cable insulation, encapsulations, die (chip) attach, thermal grease and thermal interface material .

5.2 Scope for future work

This work leaves a wide scope for future investigators to explore many other aspects of thermal behavior of particulate filled composites. For future research some recommendations are

- Effect of filler shape and size on the thermal conductivity of the composites
- Exploration of various new fillers for the development of thermally insulated materials

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